PIN PHOTODETECTOR

RELATED APPLICATION

[0001] The present application claims the benefit of U.S. Provisional Application No. 60/467,399, filed May 2, 2003, the entire contents of which are incorporated herein by reference.

BACKGROUND

[0002] The present invention generally relates to the field of photodetection. More specifically, the invention relates to the detection of photons using a semiconductor photodetector.

[0003] Owing to the known interaction between photons and electrons, advances have been made in the field of photodetectors in recent years, particularly in those photodetectors that utilize semiconductor materials. One type of semiconductor-based photodetector known as an PIN photodetector includes a number of semiconductive materials that serve different purposes such as absorption and passivation.

[0004] With many types of PIN photodetectors, the sensitivity and reliability of photodetectors degrade over time. Further, the photodetectors experience general fatigue and wear and tear. It is, therefore, desirable to present a photodetector that maintains high responsivity, high bandwidth, and low dark current over its intended lifetime, as well as being simple to fabricate.

SUMMARY OF THE INVENTION

[0005] The present invention provides a PIN photodetector including a first semiconductor contact layer, a semiconductor absorption layer having a larger area than the first semiconductor contact layer, a semiconductor passivation layer having a larger area than the first semiconductor contact layer, and positioned between the first semiconductor contact layer and absorption layer, and a second semiconductor contact layer. The semiconductor absorption layer and passivation layers are positioned between the first and second semiconductor contact layers as in Figure 1.

[0006] When the photodetector is in use, the electric field near the center of the semiconductor absorption layer is greater than the electric field near the edges of the semiconductor absorption layer as indicated in Figure 2, and the capacitance of the photodiode is also determined by the area of the first small semiconductor contact layer. The photodetector may have a 3dB bandwidth greater than 20GHz. in certain embodiments, the photodiode has a dark current behavior that is substantially constant over long time periods (e.g. 20 years) relative to an initial value.

[0007] Embodiments of the invention may have one or more of the following advantages. The configuration has an increased lifetime and improved temperature aging characteristics. The first semiconductor contact layer defines a mini-mesa structure that is advantageous for an enhanced absorption high performance, high bandwidth PIN. Moreover, the fabrication of the mini-mesa PIN photodetector is simplified since the need for a p-diffusion step to form a localized p-contact is eliminated.

[0008] Other features and advantages will be apparent from the description and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a side view of a PIN structure in accordance with an embodiment of the invention;

[0010] FIG. 2 is a graph showing the electric field profile across the absorption layer of the PIN structure of FIG. 1;

[0011] FIG. 3 is a graph showing the dark current behavior for a group of conventional mesa devices aged at 125°C with a constant voltage bias;

[0012] FIG. 4 s a graph showing the dark current behavior for a group of PIN structures of FIG. 1 aged at 175°C with a constant voltage bias;

[0013] FIG. 5 is a side view of an alternative embodiment of a PIN structure in accordance with the invention.

DETAILED DESCRIPTION

[0014] Referring now to the drawings, a photodetector, in particular, a mini mesa PIN photodetector embodying the principles of the present invention is illustrated therein and designated at 10. As its primary components, the PIN photodetector 10 includes an n+ contact layer 12, a p+ metal contact layer 14, and a p+ mini mesa 16. An InGaAs absorption layer 22 is disposed between the p+ mini mesa 16 and the n+ contact layer 12. A pair of bandgap grading layers 20 bound the InGaAs absorption layer 22. An nid ("not intentionally doped") passivation layer 18 is also disposed between the InGaAs absorption layer 22 and the p+ mini mesa 16. In particular embodiments, a passivation layer 24 is disposed on the outer

surface of the PIN photodetector 10. The passivation layer 24 may be BCB (benzocyclobutene), silicon dioxide, silicon nitride, or polyimide. An n metal contact 26 collects electrons and is positioned on the n+ contact layer 12.

[0015] Because the mini mesa 16 has a reduced area, the electric fields at the edges of the large n-mesa are substantially reduced, thus reducing the deleterious effects of any surface states or other surface defects. Furthermore, since the current is also reduced at these surfaces any charging or interface states at these boundaries is reduced.

[0016] Figure 2 shows schematically the electric field profile across the absorption layer 22 for a PIN photodetector with a 30 μm mini-mesa 16 and a 50 μm outer n-mesa. The field drops to near zero at the edges of the outer mesa which shows the passivation characteristics of the PIN photodetector 10.

[0017] These effects substantially increase the lifetime and improve the aging characteristics of photodetectors, such as APDs and undoped or low doped PINs, above that of the conventional mesa photodetector devices.

[0018] Figures 3 and 4 illustrate a comparison between the device aging characteristics of a conventional device (Figure 3) and that of the PIN photodetector 10 (Figure 4). Figure 3 shows the dark current behavior for a group of conventional mesa devices aged at the relatively low aging temperature of 125°C with a constant voltage bias. As shown, the dark current increases a factor of 20 times from the initial values in only 1500 hours, indicating a rapid degradation of these mesa devices.

[0019] Figure 4, in contrast, shows the dark current behavior for a group of mini-mesa PIN photodetectors 10 aged at the much higher aging temperature of

175°C, with a constant voltage bias. As is readily seen, the dark currents for the PIN photodetectors 10 hold steady to their initial values with little or no degradation over 5000 hours. This corresponds to a lifetime that is greater than 20 years at normal operating temperatures, such as, for example, 70°C.

[0020] One of the features of the mini mesa PIN photodetector 10 is that the capacitance of the photodetector is not significantly increased because of the larger n-mesa. Consequently, the bandwidth of the PIN photodetector 10 does not differ considerably from the bandwidth of the convention mesa PINs, as experimentally verified through a series of device measurements using a Lightwave Component Analyzer.

[0021] A comparison of the measured electrical bandwidth of the mini mesa PINs and the traditional mesa PINs shows that the 3 dB bandwidth for both a 40 micron diameter mini-mesa PIN photodetector 10, and a similar sized standard mesa PIN are both about 15GHz. Therefore, the PIN photodetector 10 has more than adequate bandwidth for OC-192 telecom applications.

[0022] Moreover, the mini mesa PIN photodetector 10 is particularly suitable for "enhanced" doped PINs, with graded doping concentrations which greatly increase the speed and sensitivity of high bandwidth PINs. In some implementations, the photodetector structure involves a grading of the p doping, such that the PIN structure is inverted with the p contact on the top and the n doping is on top, as illustrated as a PIN photodetector 110 in Figure 5.

[0023] The PIN photodetector 110 includes a p+ contact 112, such as InAlAs, an n+ metal contact 114, and an n+ mini mesa 116. In certain embodiments, the n+ mini mesa 116 is InAlAs. An absorption layer 122 which may be low doped or nid

InGaAs, is disposed between the n+ mini mesa 116 and the p+ contact 112. A pair of bandgap graded layers 120, is disposed above and beneath the absorption layer 122. The graded p+ layer 124 is disposed between the absorption layer 122 and the p+ contact 112 such that the doping concentration of the graded p+ layer 124 increases with proximity to the p+ contacts 112. An nid passivation layer 118, preferably InAlAs, is disposed between the n+ mini mesa 116 and the upper bandgap graded layer 120. A passivation 126 is disposed on the surface of the enhanced PIN 110. The passivation layer 126 may be, for example, BCB (benzocyclobutene), silicon dioxide, silicon nitride, or polymide. The p metal contact 128 is positioned on the p+ contact layer 112. This structure permits the graded p absorption layer to be as wide as the large outer contact mesa, and still have a small mini-mesa n contact to reduce capacitance and increase the bandwidth.

[0024] A simple etching process with a stop etch layer can be used to fabricate the aforementioned PIN photodetectors 10 or 110. These simple etched mini mesa structures can be reproducibly grown and fabricated, and are highly uniform over the entire wafer. The full structure is grown initially and then it is etched down to define a small localized mini mesa contact region which controls the relevant capacitance area, thus resulting in a low capacitance, high speed PIN. Thus, this design does not require a diffusion step to define the small top contact, and is therefore simpler and produces photodetectors which are more highly uniform over the entire wafer.

[0025] Note that in the PIN structures 10, 110, the high surface field near the top of the structure is very well controlled by the high bandgap passivation layers 18 and 118. As mentioned previously, these structures are high speed since the low

capacitance is determined by the area of the small mini mesa diameter and not the large noncritical isolation mesa.

[0026] The above and other implementations of the principles of the invention are within the scope of the following claims.